Interface Science of Functional Perovskites

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The performance of wireless devices could be much improved by the use of thin film materials that allow circuits to be readjusted (“tuned”) by an applied voltage. Such devices require materials that possess a voltage tunable dielectric constant. In addition, low dielectric losses are essential. We are studying a new material for these applications, bismuth zinc niobate (BZN). Thin films of this material exhibit a large tunability (55%) of the dielectric constant. At low frequencies (1 MHz), BZN thin films also exhibit very low losses ($\tan \delta < 10^{-3}$). In bulk form, BZN was thought not to be suitable for high-frequency applications, due to a dielectric relaxation, which causes an increase in loss at GHz (microwave) frequencies. We have discovered that tensile stresses, imposed on a thin film by a substrate with a suitable thermal mismatch, cause the dielectric characteristics to change such that low losses are maintained into the GHz frequency range (Fig. 2).

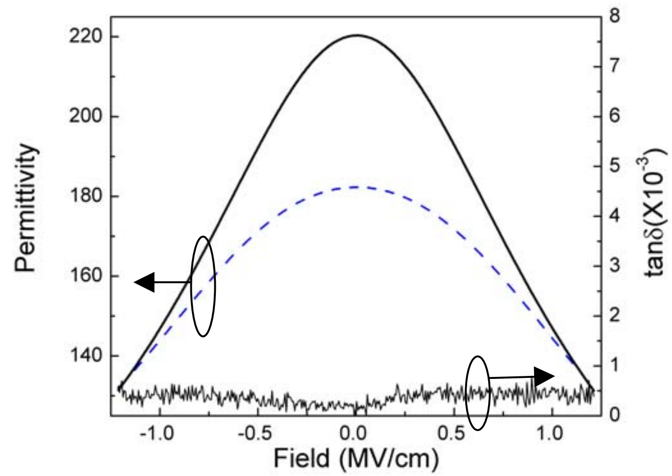

Figure 1: Voltage tunable dielectric constant of BZN thin films on two different substrates: sapphire (dashed line) and Si (solid line). The dielectric loss on sapphire is also shown.

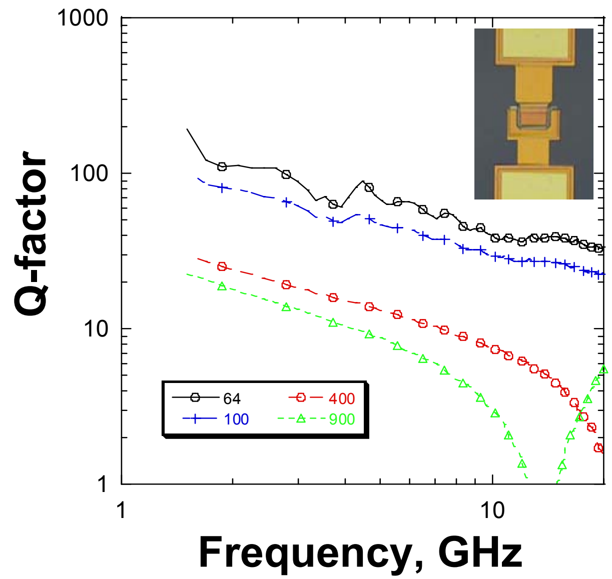

Figure 2: Total device quality factor (inverse of the loss tangent) measured at microwave frequencies of a voltage tunable capacitor (inset) with a BZN film dielectric (collaboration with R.A. York’s group at UCSB). The different curves are measurements for devices with different areas (64-900 μm^2).

Introduction:

High-permittivity thin films are being investigated for applications in integrated high-density storage devices, decoupling capacitors and novel electric-field tunable devices operating at high frequencies. For these applications, films need to combine a high permittivity with low dielectric losses (tan ∂). However, ferroelectric thin films, such as $(Ba,Sr)TiO_3$ (BST), currently considered for these applications, exhibit a significant drop in permittivity when the film thickness is decreased. The loss tangent of the best reported BST films is around 5×10^{-3}. We are studying an alternative, non-ferroelectric material, $Bi_{1.5}Zn_{1.0}Nb_{1.5}O_7$ (BZN)

Research Results:

Near-stoichiometric BZN films were deposited by radio-frequency (rf) magnetron sputtering. BZN films with thicknesses in the range of 160-170 nm exhibited electric field tunable permittivities up to 220, and dielectric loss tangents less than 5×10^{-4}. A maximum applied bias field of 2.4 MV/cm resulted in a ~ 55% tunability of the dielectric constant. Bulk BZN shows a low temperature dielectric relaxation that is associated with a dielectric loss peak . This loss peak shifts to higher temperatures at higher measurement frequencies, approaching room temperature in the microwave frequency region. In contrast, the dielectric relaxation was shifted to temperatures below 80 K (at 1 MHz) in BZN films on vycor that were under a large tensile stress. This shift reflected a lowering of the activation energy of the dielectric relaxation processes due to tensile stress. It is expected that films under large tensile stress require higher frequencies than bulk BZN to shift the dielectric relaxation to room temperature, which makes these films attractive for low-loss, high-frequency applications. A possible explanation for the stress effects are that tensile stresses change the distances between the hopping ions or change the dipolar interaction, but further studies are needed. Microwave measurements were carried out in collaboration with Prof. York's group at UCSB. BZN films in capacitors on vycor substrates showed a permittivity of ~ 188 and losses below 1.5×10^{-3} up to 10 GHz. The low losses are consistent with our previous predictions that tensile stresses in BZN films favorably influence the loss behavior at high frequencies.

Significance:

Wireless communication, such as cell phones, is widely used. The discovery of new voltage tunable dielectric materials with low losses at microwave frequencies would allow improved performance and further miniaturization of wireless communications. Our results are of scientific significance because they show that tensile stresses may be used to achieve low dielectric losses in a material that may otherwise not have shown low losses at high frequencies. The mechanism of coupling between stress and dielectric relaxation in this material is not yet understood and requires further studies, which are underway.

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Education:

The program partially supports one graduate student (Mr. Jiwei Lu). Over the summer, our group hosted an undergraduate research intern, Ms. Lia Bregante. Ms. Bregante performed atomic force microscopy studies of ferroelectric thin films under the supervision of an IGERT graduate student (Mr. Sean Keane) and participated in activities of the MRL RISE program, including scientific presentations of her work.

Outreach:

Professor Stemmer presented several talks on novel oxide thin films at outreach symposia. She also participated in panel discussions and a mini-conference with students and faculty from minority serving institutions on the experience of being a female faculty member and on promoting intercampus collaborations (both were organized by the NSF-funded UC-HBCU AGEP partnership).